Search for GMSB SUSY with ATLAS

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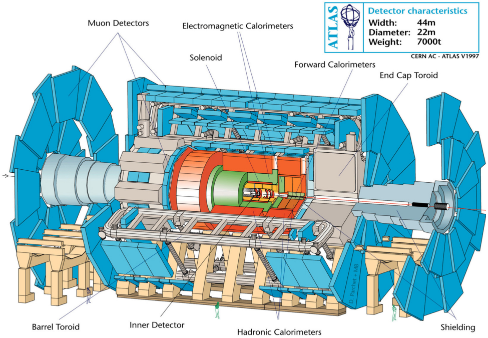
Outline

- short description of GMSB
- GMSB with τ final states (GMSB6)
  - selection for 10 TeV
  - parameter scan
  - invariant mass
- GMSB with γ final states (GMSB1-3)
  - mass measurements
  - non-pointing photons
  - parameter determination



GMSB

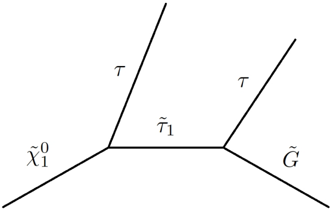
- Gauge Mediated Supersymmetry Breaking
- breaking: coupling of messenger particles
- messenger particles give mass to the super partners of the SM particles through gauge interaction
- assumption: R-parity conservation

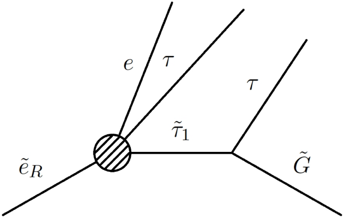
Parameters

- Λ - SUSY breaking mass scale; determines predominantly masses of SUSY particle
- M_{mes} - mass of messenger particles
- N_5 - number of messenger fields, masses of gauginos and sleptons/ squarks scale differently in N_5
  - $N_5 = 1$ NLSP: $\tilde{\chi}_1^0$, $\tilde{\tau}_1$ (GMSB1-3)
    $N_5 = 3$ NLSP: $\tilde{e}_R, \tilde{\mu}_R, \tilde{\tau}_1$ (GMSB6)
  - NLSP also depends on $\tan\beta$
- $\tan\beta$ - ratio of vacuum expectation values of the two Higgs fields
- $\text{sgn}\mu$ - sign of the Higgsino mass term
- C_{grav} - scale factor for the gravitino mass; determines NLSP lifetime

GMSB with τ final states

(D. Ludwig)

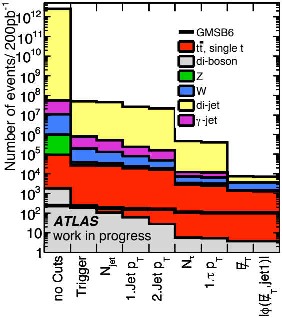




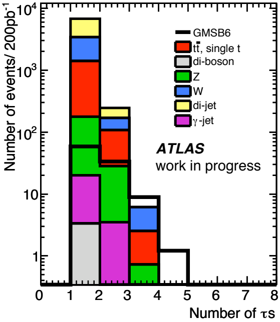
Preselection

- Trigger: $p_{T,jet1}$ and $\not{E}_T$
- jets: $N_{jets} \geq 2$, $p_{T,jet1} > 100\,GeV$, $p_{T,jet2} > 50\,GeV$, overlap removal w/ τ
- τ: $N_\tau \geq 1$, $p_{T,\tau 1} > 20\,GeV$, reco. of hadr. τ-decays, overlap removal w/ e
- $\not{E}_T > 60\,GeV$
- $|\Delta\phi(\not{E}_T, p_{T,jet1})| > 0.2$
- dominant residual BG: $t\bar{t}$, $W \to \tau\nu$, assumed uncertainty of 50%

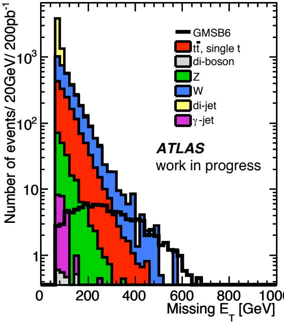
Cutflow



N_τ (after cuts)



$\not{E}_T$ (after cuts)



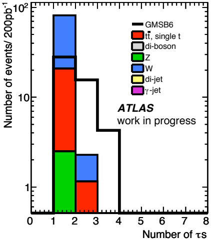
Two-dimensional Optimization for GMSB6

- significance definition

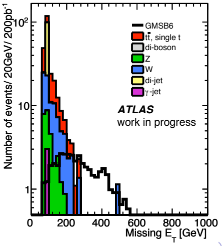
$$Z_n = \sqrt{2}\,\mathrm{erf}^{-1}(1-2p)$$
$$p = A\int_0^\infty db\, G(b; N_b; \delta N_b) \sum_{i=N_{Data}}^{\infty} \frac{e^{-b} b^i}{i!}$$

  - $N_{Data} = S + BG, N_b = BG, \delta N_b = 50\% + \delta_{MC}$
  - erf^{-1}: inverse error function
  - p: probability that BG b fluctuates to number of measured events N_{Data}
  - $G(b; N_b; \delta N_b)$: gaussian distribution of MC BG
  - A: normalization factor
- maximum for $N_\tau \geq 2$ and $\not{E}_T > 280\,\mathrm{GeV}$ $\Rightarrow$ final selection
- $Z_n(200\mathrm{pb}^{-1}) = 5.7$

N_τ ($\not{E}_T > 280$ GeV)

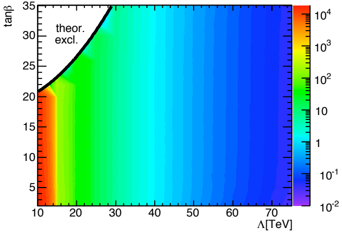


$\not{E}_T$ ($N_\tau \geq 2$)



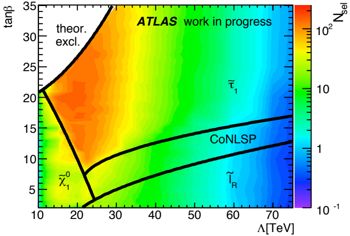
Parameter Scan

Total GMSB cross section (in pb)



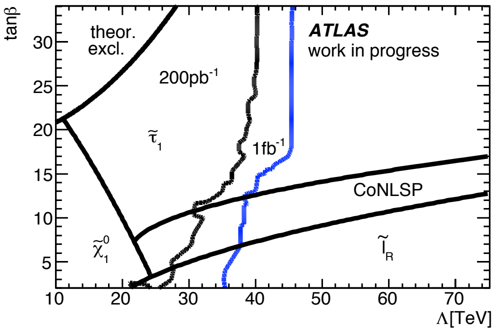
- cross section
  - decreases with Λ due to increasing SUSY masses
  - dependence on $\tan\beta$ small

Number of selected events



- number of selected events $(200\,\mathrm{pb}^{-1})$
  - decrease with Λ due to decreasing cross section
  - increase with $\tan\beta$ depending on NLSP

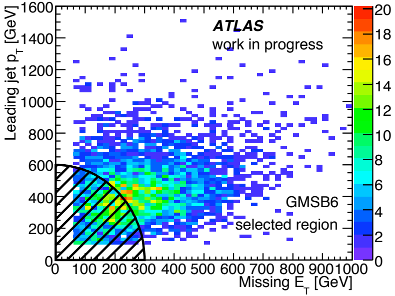
Integrated Luminosity needed for 5σ Discovery



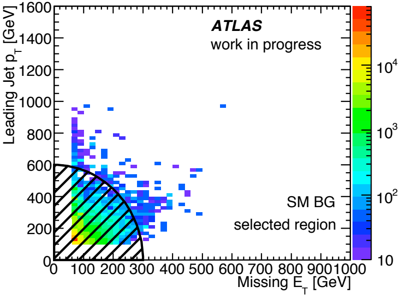
- discovery potential high for small Λ and bigger for higher $\tan\beta$
- discovery with first data
- $200\,\mathrm{pb}^{-1}$: $\Lambda \leq 40\,\mathrm{TeV}$
- $1\,\mathrm{fb}^{-1}$: $\Lambda \leq 45\,\mathrm{TeV}$
- further discovery limited by MC statistic

Selection for Invariant Mass Study

Signal



SM BG



- $\mathcal{L} = 8\,\mathrm{fb}^{-1}$
- standard SUSY preselection (cf. S. 6)
- final selection
  - $N_\tau \geq 2$
  - $\left(\frac{\not{E}_T}{300\,\mathrm{GeV}}\right)^2 + \left(\frac{p_T^{\mathrm{leading\,jet}}}{600\,\mathrm{GeV}}\right)^2 > 1$
- signal events enhanced by a factor of 1.5 wrt. selection for discovery

Invariant Mass

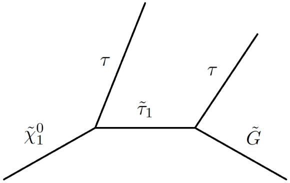
- invariant mass of $2\tau \rightarrow$ mass edge

$$M^2_{\tau\tau,\max} = \frac{(m^2_X - m^2_{\tilde{\tau}_1})(m^2_{\tilde{\tau}_1} - m^2_{\tilde{G}})}{m^2_{\tilde{\tau}_1}}$$

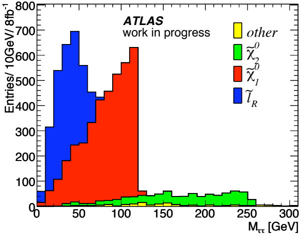
$$\xRightarrow{m_{\tilde{G}}=2.4\text{eV}}$$

$$M^2_{\tau\tau,\max} = m^2_X - m^2_{\tilde{\tau}_1}$$

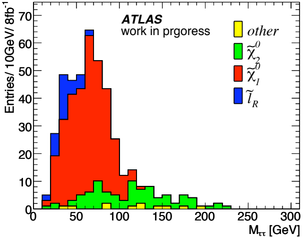
$$M_{\tau\tau,\max} = \sqrt{m^2_{\tilde{\chi}^0_1} - m^2_{\tilde{\tau}_1}} = 120.6\,\text{GeV}$$



Invariant mass of 2τ
(Generator Level)

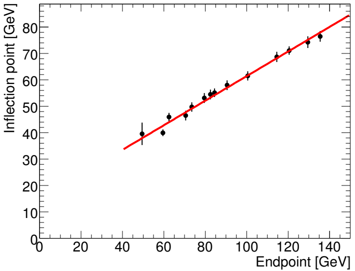


(Reconstruction Level)



Determination of the invariant mass endpoint

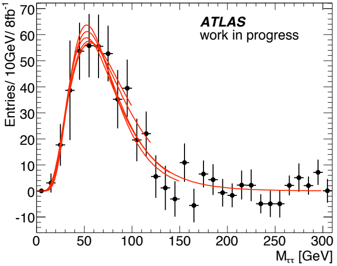
- invariant mass endpoint cannot be measured directly
- measure inflection point and calibrate
- calibration curve determined through mSUGRA ATLFAST samples, $\tilde{\chi}_1^0$ contribution only (*Zendler et al.*, arXiv:0901.0512)



- reconstruction works even with $\tilde{\chi}_2^0$ and $\tilde{\ell}_R$ contributions
- fit of reconstructed invariant mass (OS-SS) including background

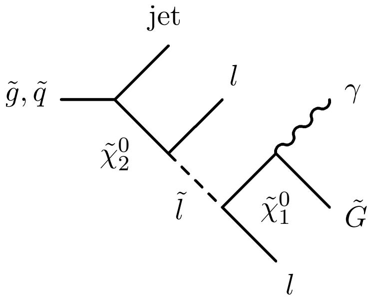
$$M_{\tau\tau,\max} = 135.0 \pm 4.3^{(\text{stat.})}\,{}^{+17.9(\text{syst.})}_{-15.8}\ \text{GeV}$$

- syst. error: BG, fit range, calibration, contribution from $\tilde{\chi}_2^0$ and $\tilde{\ell}_R$



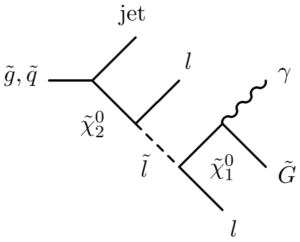
GMSB with γ final states

(M.Terwort)



Discovery Potential for GMSB1-like Scenarios

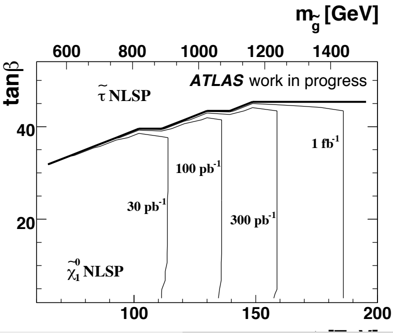
- NLSP: $\widetilde{\chi}_1^0$
- $\widetilde{\chi}_1^0 \Rightarrow \gamma\widetilde{\mathrm{G}}$
- $\mathrm{C_{grav}} = 1 \Rightarrow$ prompt photons
- $\mathrm{C_{grav}} > 1 \Rightarrow \widetilde{\chi}_1^0$ finite lifetime, non-pointing photons



Selection:

- $\not{E}_{\mathrm{T}} > 60\,\mathrm{GeV}$
- jets: $\mathrm{N_{jets}} \geq 4$, $\mathrm{p_{T,jet1}} > 100\,\mathrm{GeV}$, $\mathrm{p_{T,jet2/3/4}} > 50\,\mathrm{GeV}$
- $|\Delta\phi(\not{E}_{\mathrm{T}}, \mathrm{p_{T,jet1/2/3}})| > 0.2$
- γ: $\mathrm{N}_\gamma \geq 2$

Discoverypotential (14 TeV)

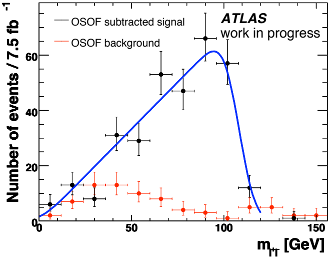


Mass measurements

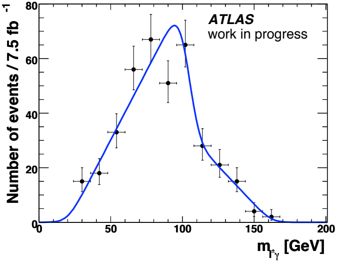
SUSY masses can be determined via invariant mass distributions.

- Benchmark scenario GMSB2 (decay length: $\simeq$ 1m)
- Event selection:
  - similar to discovery study
  - $N_{jets} \geq 2$, $N_\ell \geq 2$
- select OSSF lepton pairs
- subtract OSOF BG
- fit linear functions smeared with Gaussian $\Rightarrow$ measure kinematic endpoints of $M_{\ell\ell}$, $M_{\ell\gamma}$ und $M_{\ell\ell\gamma}$
- fitted masses:
  $m_{\tilde{\chi}_1^0} = 114.0 \pm 9.5\,\mathrm{GeV}(118.8\,\mathrm{GeV})$
  $m_{\tilde{\ell}} = 154.1 \pm 8.0\,\mathrm{GeV}(160.5\,\mathrm{GeV})$
  $m_{\tilde{\chi}_2^0} = 222.5 \pm 6.3\,\mathrm{GeV}(225.5\,\mathrm{GeV})$

Fit of $M_{\ell\ell}$



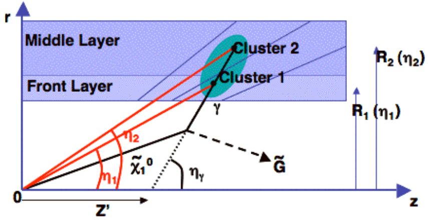
Fit of $M_{\ell\gamma}$



Non-pointing photons

- NLSP can have finite lifetime
- non-pointing photons in final state
- standard selection based on shower variables inefficient

Non-poiting photon in calorimeter



Problems:

- efficient separation of signal and BG
- determination of NLSP lifetime
  boost of $\tilde{\chi}_1^0$ unknown, reconstruction of ϕ-direction impossible

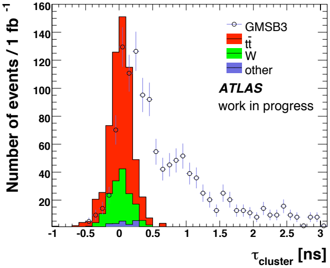
Idea:

- use calorimeter timing (resolution: a few 100ps) and projection of photon path on z-axis as additional discriminating variables
- fit distributions to separate signal from background
- measure $\tilde{\chi}_1^0$ lifetime with calibration curve

Cluster timing and combined fit

- Benchmark scenario GMSB3 (decay length: $\simeq$3m)
- event selection similar to discovery study
- dominant SM background: $t\bar{t}$
- signal: Landau distribution, BG: Gauss

Clustertime of γ

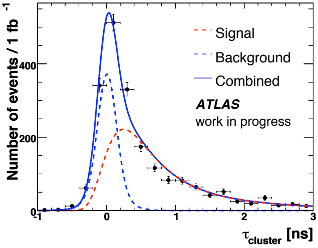


- measure resolution with Z→ee data
- use parameters to model background
  ⇒ reduction of free parameters
- fit combined model

Idea:

- use width for calibration curve
  ⇒ simulate different decay lengths

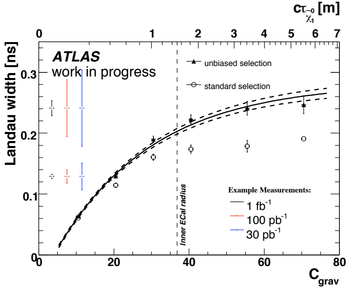
Combined Fit



Calibration and results

Fit of calibration curve

- saturation effect due to decreasing ID-efficiency and finite detector size $\Rightarrow$ statistical error increases significantly with lifetime
- dependence on other GMSB parameters $\approx$ stat. fluctuations
- only small dependence on BG scaling



Results

- systematic uncertainties:
  - limited MC statistics
  - BG parametrization with Z→ee
- the larger the lifetime, the larger the uncertainty due to saturation effect
- measurement of $\tilde{\chi}_1^0$ lifetime possible with good precision

Example fit values

theo. C_{grav}	measurement $C_{grav} \pm$ stat. $\pm$ sys.
10	$10.6 \pm^{0.2}_{0.2} \pm^{0.2}_{0.2}$
20	$19.9 \pm^{0.6}_{0.6} \pm^{0.5}_{0.4}$
30	$32.9 \pm^{1.6}_{1.5} \pm^{1.2}_{1.1}$
40	$44.2 \pm^{3.4}_{3.0} \pm^{2.6}_{2.2}$
55	$53.6 \pm^{8.2}_{6.2} \pm^{4.7}_{3.5}$
70	$57.5 \pm^{13.8}_{8.9} \pm^{5.9}_{4.3}$

Parameter determination

- Can the theory parameters be determined with the measured observables? ⇒ perform a fit of the model to the neutralino lifetime and invariant mass endpoints.
- use fitting package fittino for the fit and spectrum calculator SPheno for theory predictions

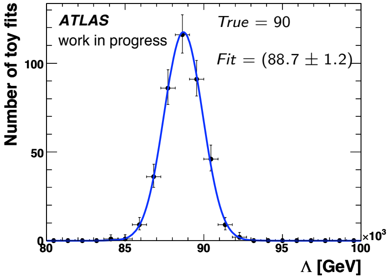
Par.	Description
Λ	enters masses linearly
M_{mes}	enters masses logarithmically lifetime with sqrt
N_5	fixed to 1 due to γ final states
sgn(μ)	fixed to 1 due to SM fit
tanβ	does not enter directly the measured observables
C_{grav}	enters lifetime with sqrt

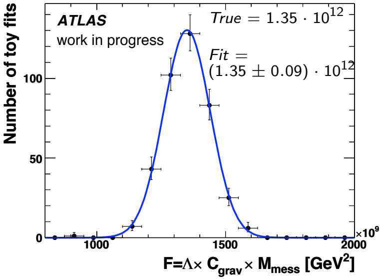
Expectation:

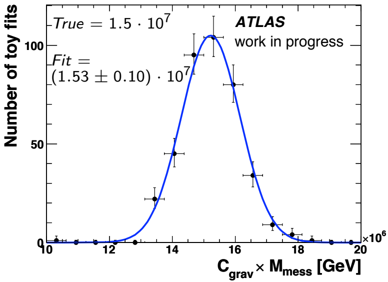
- Λ can be measured well
- M_{mes} and C_{grav} can only be measured as a product
- tanβ cannot be measured

Parameter determination

- fit a GMSB model to ”real” measurements with realistic uncertainties
- choose GMSB2 due to better lifetime measurement
  $\Rightarrow \Lambda$ and $M_{mes} \cdot C_{grav}$ determined
  $\Rightarrow$ breaking scale $F = \Lambda \cdot M_{mes} \cdot C_{grav}$







Conclusion

GMSB6 with τ final states:

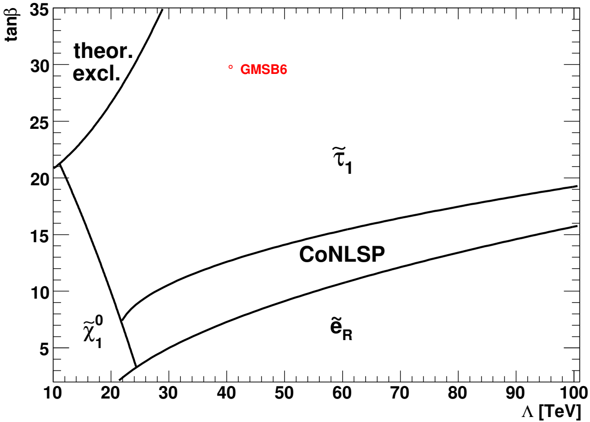
- study of discovery potential with $\sqrt{s} = 10\,\text{TeV}$ in GMSB6
  - N_τ and $\not{E}_T$ allow efficient separation of signal and background
  - discovery possible with first data
  - reasonable range of parameter space can be covered
- determination of invariant mass endpoint possible

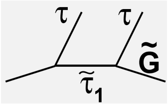
GMSB1-3 with γ final states:

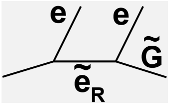
- GMSB can provide non-pointing photons in calorimeter
  - use ECAL timing to measure NLSP lifetime
- use kinematic endpoints to measure masses
- fit of model partially possible
  - determination of breaking scale

NLSP in GMSB

- LSP (Lightest Supersymmetric Particle)
  - nearly massless, neutral Gravitino $m(\tilde{G}) = \mathcal{O}(eV)$
- NLSP (Next-to-Lightest Supersymmetric Particle)
  - determines phenomenology







GMSB 6:
$\Lambda = 40$ TeV
$\tan\beta = 30$
$M_{mes} = 250$ TeV
$N_5 = 3$

Fast Simulation Samples

- 380 points for $10\,\mathrm{TeV} \leq \Lambda \leq 100\,\mathrm{TeV}$ and $2 \leq \tan\beta \leq 35$
- $\mathrm{M_{mes}} = 250\,\mathrm{TeV}, \mathrm{N_5} = 3\,, \mathrm{C_{grav}} = 1$
- 10 000 events per point